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# Relaxation losses in 7/16 in. Diameter special grade prestressing strands, June 1969

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Prestress Losses  
Progress Report No. 3

**RELAXATION LOSSES IN  
7/16 in. DIAMETER SPECIAL GRADE  
PRESTRESSING STRANDS**

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by  
Erhard Schultchen  
Ti Huang

Fritz Engineering Laboratory Report No. 339.4

FRITZ ENGINEERING LABORATORY INSTITUTE OF RESEARCH

Project 339

PRESTRESS LOSSES IN PRE-TENSIONED  
CONCRETE STRUCTURAL MEMBERS

Progress Reports Completed to Date

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- 1 COMPARATIVE STUDY OF SEVERAL CONCRETES REGARDING THEIR  
POTENTIALS FOR CONTRIBUTING TO PRESTRESS LOSSES.  
Rokhsar, A. and Huang, T., F. L. Report 339.1, June 1968
- 2 CONCRETE STRAINS IN PRE-TENSIONED CONCRETE STRUCTURAL  
MEMBERS - PRELIMINARY REPORT. Frederickson, D. and  
Huang, T., F. L. Report 339.3, June 1969
- 3 RELAXATION LOSSES IN 7/16 in. DIAMETER SPECIAL GRADE  
PRESTRESSING STRANDS. Schultchen, E. and Huang, T.,  
F. L. Report 339.4, July 1969

RELAXATION LOSSES IN  
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PRESTRESSING STRANDS

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Erhard Schultchen

Ti Huang

This work was conducted as part of the project "Prestress Losses in Pre-Tensioned Concrete Structural Members", sponsored by the Pennsylvania Department of Highways and the U. S. Bureau of Public Roads. The opinions, findings, and conclusions expressed in this report are those of the authors, and not necessarily those of the sponsors.

Department of Civil Engineering  
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July 1969

Fritz Engineering Laboratory Report No. 339.4

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TABLES    AND    FIGURES

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## ABSTRACT

In this report are presented the preliminary results of experiments conducted to investigate the relaxation loss characteristics of prestressing strands. This study is part of the research project "Prestress Losses in Pre-Tensioned Concrete Structural Members", sponsored by the Pennsylvania Department of Highways and the U. S. Bureau of Public Roads.

The four main variables of this relaxation study are size and type of strands, initial stress level, manufacturer and type of loading.

A description of the test set-up and the test procedure are given in this report. The data obtained during the first 200 days for 14 prestressing strands with nominal diameter 7/16 in. are presented. For this duration no significant difference was found between the two manufacturers.

## 1. INTRODUCTION

The purpose of Project 339, entitled "Prestress Losses in Pre-tensioned Concrete Structural Members", is to investigate a number of factors which influence the loss of prestressing force in pre-tensioned concrete members.

The contributions to the total prestress loss can be categorized in two major groups:

- (1) prestress loss caused by concrete and
- (2) prestress loss caused by steel

Of these two only the latter will be discussed in this report.

Prestress loss caused by steel, or relaxation of steel as it is most commonly referred to, occurs due to the fact that steel, as any other material, undergoes a plastic deformation when subjected to an external load. This plastic flow, normally negligible in steel design, becomes significant for high-strength steel when continuously subjected to high stresses as in the case of prestressing tendons. Relaxation of steel is a long-time phenomenon, and generally does not become complete within convenient time intervals for experimental studies. Nevertheless, due to its highly asymptotic character, it is believed possible to achieve a reasonably good estimate of the relaxation loss for the life of prestressed concrete members, say 50 years, based on experimental data over a period of two to three years, by means of a carefully selected testing program.



## 2. TEST VARIABLES

The four main variables in this relaxation study of prestressing strands are the following:

- (1) Manufacturer
- (2) Type and size of strands
- (3) Initial stress level
- (4) Type of loading

In the following sections the effects of each of these test variables are discussed and their variations used in this study are described.

### (1) Manufacturer

Although prestressing strands from all manufacturers are subjected to ASTM standards and specifications, minor differences in the chemical composition of steel as well as different methods of cold working and forming could cause the relaxation characteristics to be different. Therefore, prestressing strands from all principal suppliers for Pennsylvania were included in this study. These manufacturers are: Bethlehem Steel Corporation, CF&I Steel Corporation, and United States Steel Corporation.

### (2) Type and Size of Strands

The most commonly used pre-tensioning tendons for highway bridge members are 7-wire stress-relieved strands of the special grade (270 k). Taking into account current and possible future

applications, strands with nominal diameter of 7/16 in. as well as 1/2 in. were included in this investigation.

(3) Initial Stress Level

Results from previous investigations\* show that the initial stress level, is the most important factor influencing the relaxation losses in steel. Three values of initial stress were chosen to encompass the usual stress range in prestressing strands, namely 80, 65, and 50 percent of the specified tensile strength.

The high value of 80 percent specified strength is only slightly below the conventional yield strength of the strand, and represents a practical upper limit of initial prestress. The 50 percent stress level is selected to represent a lower bound of steel stress, below which the relaxation loss is generally considered negligible. The intermediate stress level of 65 percent is chosen to be close to the stress in steel after anchorage under the current practice. In the investigation of 1/2 in. strands an additional stress level of 70 percent is used. The purpose of this additional stress level is to detect any change of behavior of the strands at the currently specified working stress level.

\*See Lin: "Design of Prestressed Concrete Structures"  
John Wiley & Sons, Inc., 1967

#### (4) Type of Loading

There are basically two ways to describe or to investigate the plastic flow of materials in a long-time study:

1. Constant length tests (relaxation tests)
2. Constant load tests (creep tests)

Relaxation refers to the time depending decrease of stress in a material subjected to a constant strain, while creep represents the time depending increase of strain under a constant stress. Therefore, the data obtained from a constant load test are strain quantities (creep strain), whereas the results of relaxation tests are given in form of stress quantities (prestress loss).

The actual situation which occurs in a concrete specimen is different from both types of loading. Concrete undergoes a plastic deformation under sustained loading, hence the strain will not remain constant as in a relaxation test. On the other hand, the gradual changes of length cause the steel stress to decrease, thus contradicting the basic condition of the creep phenomenon. It is generally accepted that specimens tested under relaxation type of loading (constant strain, decreasing stress) approach the actual behavior (decreasing strain, decreasing stress) more closely than those tested under constant load (increasing strain, constant stress), therefore the majority of specimens in this investigation will be tested in the former manner. An additional reason for this decision is that this type of tests is easier to perform.

Theoretically, it should be possible to convert

relaxation test data into constant load test results or into data obtained from tests with a specified time-depending change of strains. To verify the results of such computations a number of constant load as well as simulation tests will be performed.

### 3. TEST SET-UP

The set-up for the relaxation tests consists of a 10 feet long loading frame, built up from two 6 in. x 4 in. x 1/2 in. angles with long legs 3/4 in. apart. The strand is placed at the centroid of this double-angle section and anchored to 1 in. end plates by means of strand chucks. At the jacking end of the frame, the end plate and the strand chuck are separated by a load cell and a device for the control of the initial strain in the specimen (Fig. 1). This device is composed of a number of spacers, D, and an adjustment bolt, B, which screws into the end bearing Plate A.

The load cells are specially made for this investigation. They consist of 5 in. long 20-14 TG aluminum alloy hollow cylinders with an inner diameter of 7/8 in. and an outer diameter of 1-3/4 in. Eight EA-13-125TM-120 type strain gages are mounted on the outside of each cylinder, four in the longitudinal direction, and four lateral. These strain gages are connected into two independent Wheatstone bridges. Strain readings are taken from the bridges by a Bean digital strain indicator (Model 206B). Each unit of the readings corresponds to approximately 8 pounds of force, less than 0.06 percent of the initial tension in the specimen. Since the zero readings of load cells under long duration loads tend to drift for a number of reasons, a jacking arrangement has been designed which allows a complete unloading of the built-in load cell. In this way, it is possible to make necessary zero connections and to improve the accuracy of test

data significantly.

The procedure of taking readings at selected intervals of time thus includes three steps:

1. Taking readings on the (loaded) load cell
2. Unloading the load cell by means of the jacking device, taking zero readings
3. Taking readings on the re-loaded load cell

Theoretically, it should be possible to completely relieve the load cell without affecting the tension in the strand. In practice, because of the elastic rebound of the aluminum material, it is necessary to apply a slightly higher force to do so. However, the difference is very small, in the neighborhood of 200 to 300 pounds, and the effect on the relaxation loss is considered negligible.

The method of measuring the force during the initial stretching of the specimen differs from the procedure described above insofar as an additional external load cell, G, is used for this purpose (Fig. 1). Originally, it was planned to use this external load cell each time the strand force is measured, thus providing four independent measurements of the load. However, it was quickly found that the external load cell does not yield as consistent results as the internal load cells. Two sources contributing to biased reading from the external cell are suspected:

1. the elastic response of the internal load cell and the spacers during the unloading process cause a difference between the tensile force in the strand and the force needed for the release of the internal cell

2. the point at which the internal load cell becomes unloaded is extremely difficult to establish and thus subjected to errors

Therefore, all data obtained in this relaxation study are based on the more accurate readings of the internal load cell.

To omit another possible source of error, dial gage readings are taken during an initial period of 2 weeks to measure the relative displacement between the strand and the end-bearing plates. In this way a possible slippage of the strand chucks can be measured and taken into account.

#### 4. TEST RESULTS, DISCUSSION, AND CONCLUSIONS

A total of 14 7/16 in. specimens have been tested so far in the investigation. Included are specimens from two manufacturers, each of which are tested at three different levels of initial stress (Table 1). The third manufacturer was unable to supply strands of the size at the time, and therefore was not included in this report. The data obtained from these tests during the first 200 days are presented in Figs. 2 to 8.

Figs. 2 to 7 contain the prestress loss versus time relationship obtained from series of two or three repetitive specimens and give an indication of the typical scattering of data. The solid line in this graph represents a five-term expression of the following form:

$$\Delta f_s = a_\sigma + a_1 t + a_2 \sqrt{t} + a_3 t^2 + a_4 \log t$$

where the coefficients  $a_\sigma$  .....  $a_4$  were determined by the method of least squares based on all measured values for this series. The purpose of using such a rather unhandy expression was to reveal all features of the observed relaxation behavior without referring directly to data points. It can be seen from the figures that the five-term expressions approximate the observed data quite clearly. The standard deviations for all series varied within the range of from 0.20 to 0.35 percent of the initial stress.

Fig. 8 contains the relaxation loss vs. time curves for



the six series of specimens. Two preliminary conclusions can be drawn from this figure:

- (1) The relaxation loss depends strongly on the initial stress in the strand
- (2) The loss characteristics of strands from the two manufacturers do not differ significantly during the first 200 days

A tendency of "bending over", i.e. a decreasing rate of relaxation loss can be observed for most of the specimens after approximately 100 days. Data available at the time of this writing are insufficient for any definite trend to be established, since the upper parts of these relaxation-time curves are rather sensitive to new data points. For this reason, it is not recommended to venture any long-term prediction from the information presented in this report.

## 5. ACKNOWLEDGEMENTS

This study is part of a research project on the prestress losses of pre-tensioned concrete structural members, which is being conducted at the Fritz Engineering Laboratory, Department of Civil Engineering, Lehigh University. Professor D. A. VanHorn is the Chairman of the Department. Professor L. S. Beedle is the Director of the Fritz Engineering Laboratory.

The sponsors of this research project are the Pennsylvania Department of Highways and the U. S. Bureau of Public Roads.

Acknowledgements are gratefully paid to the three manufacturers of prestressing strands who supplied the testing material.

Special thanks are also extended to Mr. J. M. Gera for preparing the graphs, and to Mrs. A. L. Silfies for her patience in typing this report.

## 6. TABLES AND FIGURES

Table 1 Specimens for Relaxation Tests

Nominal diameter 7/16 in.

Total number of specimens 21

Stress Level (% $F_u$ )	Manufacturer		
	AB	AC	AU
50	(2)	2	2
65	(3)	3	3
80	(2)	2	2

NOTE: Specimens marked by ( ) have not yet been tested

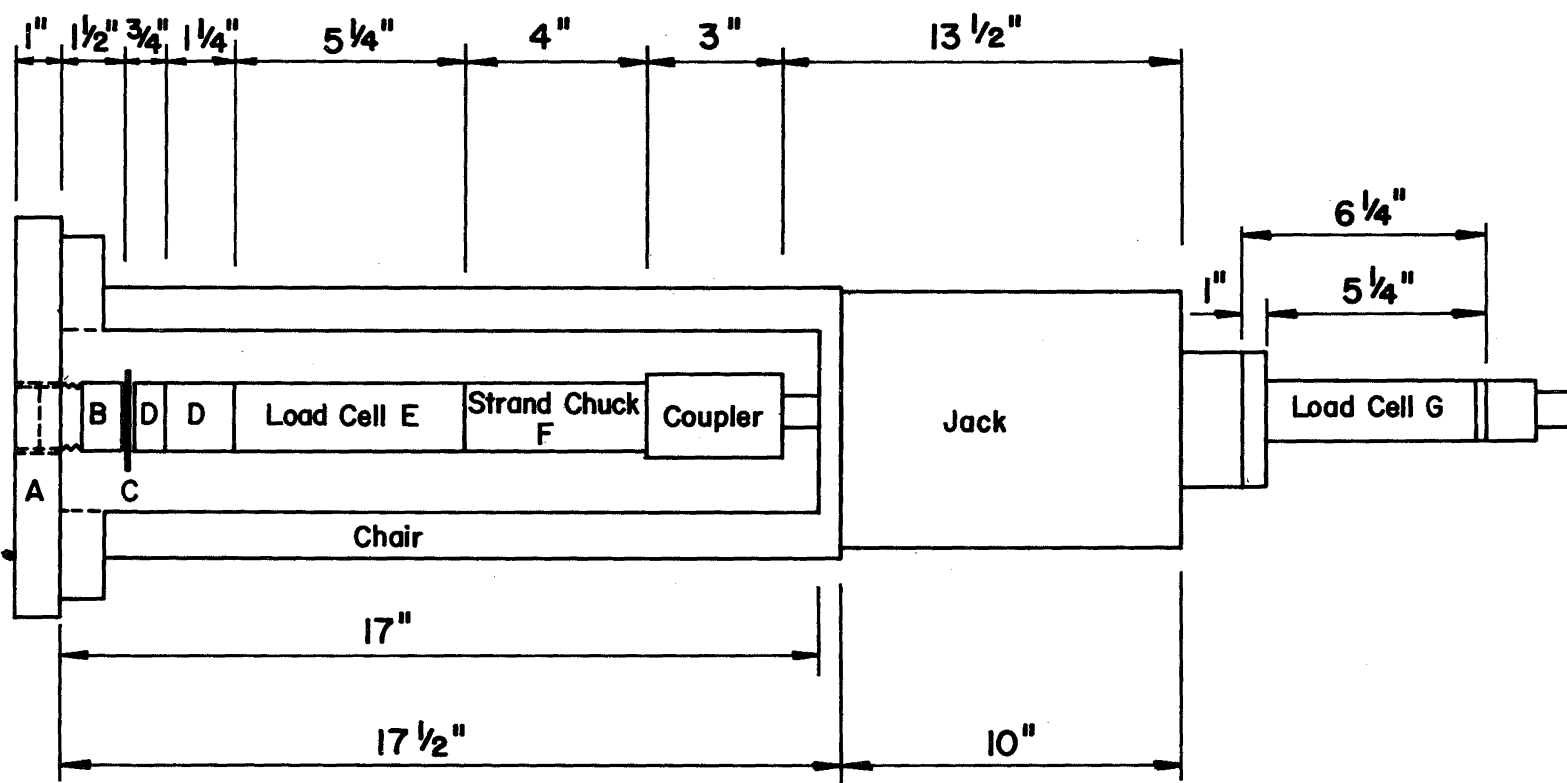


Fig. 1 Jacking and Measuring Assembly

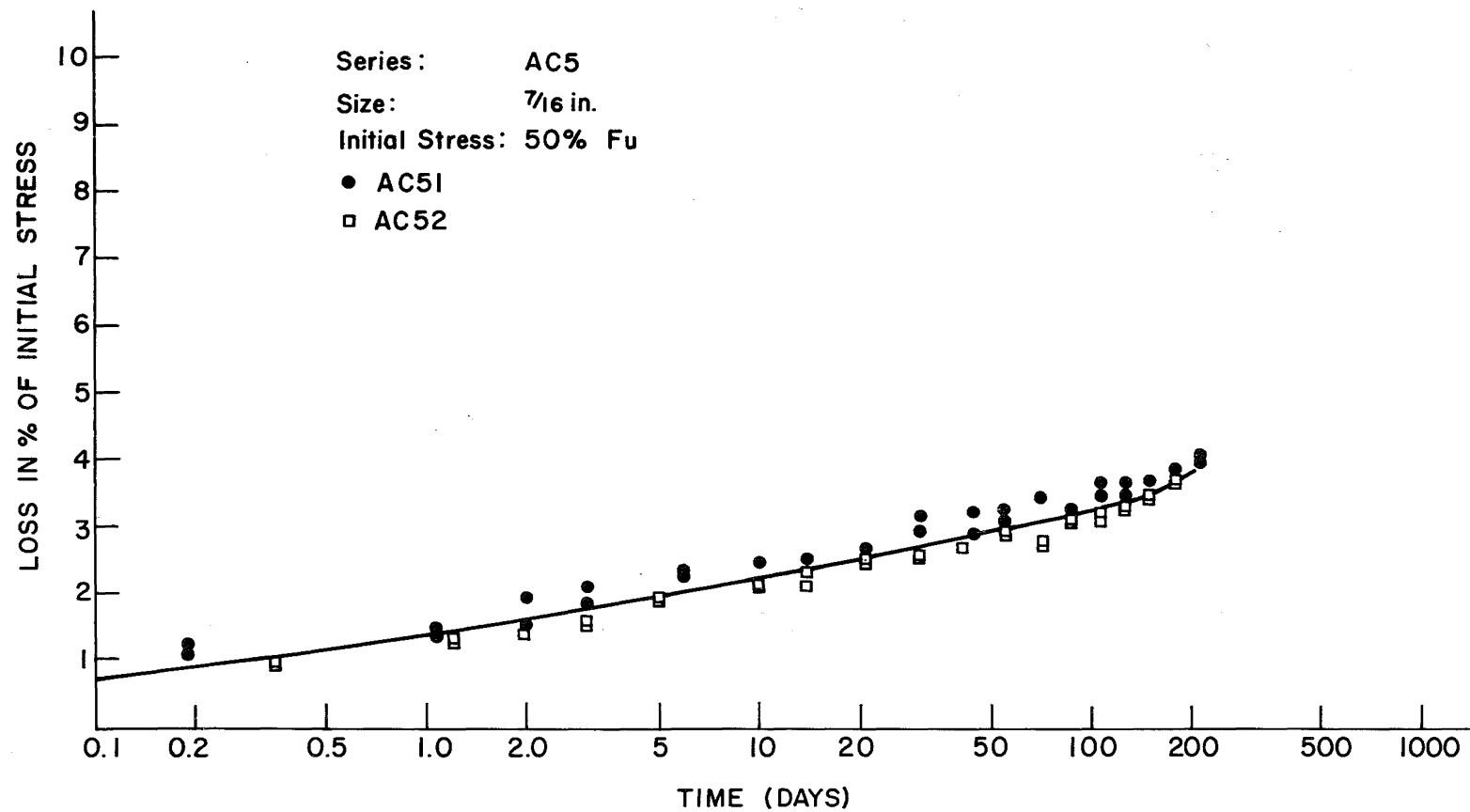


Fig. 2 Relaxation Loss Data Series AC5

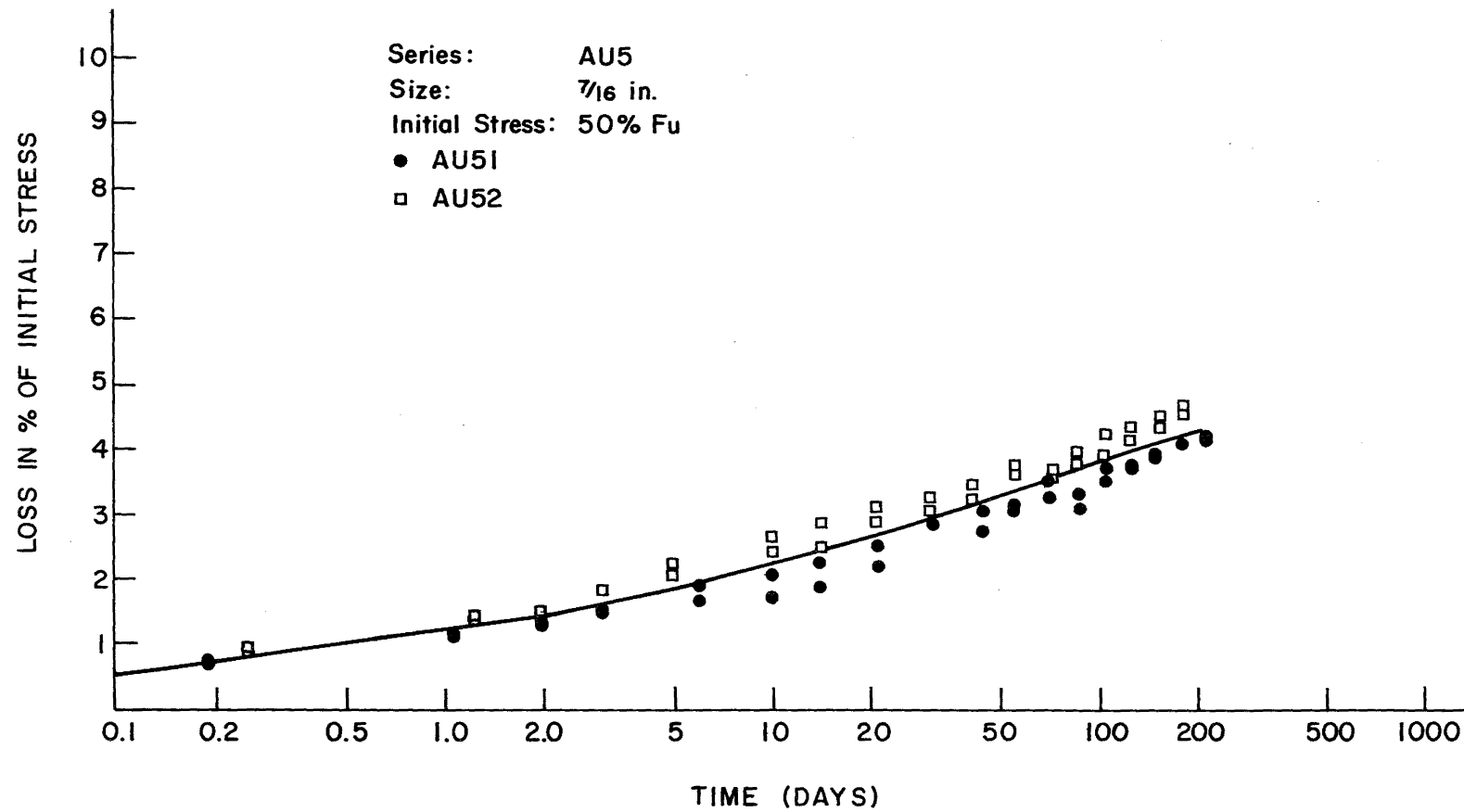


Fig. 3 Relaxation Loss Data Series AU5

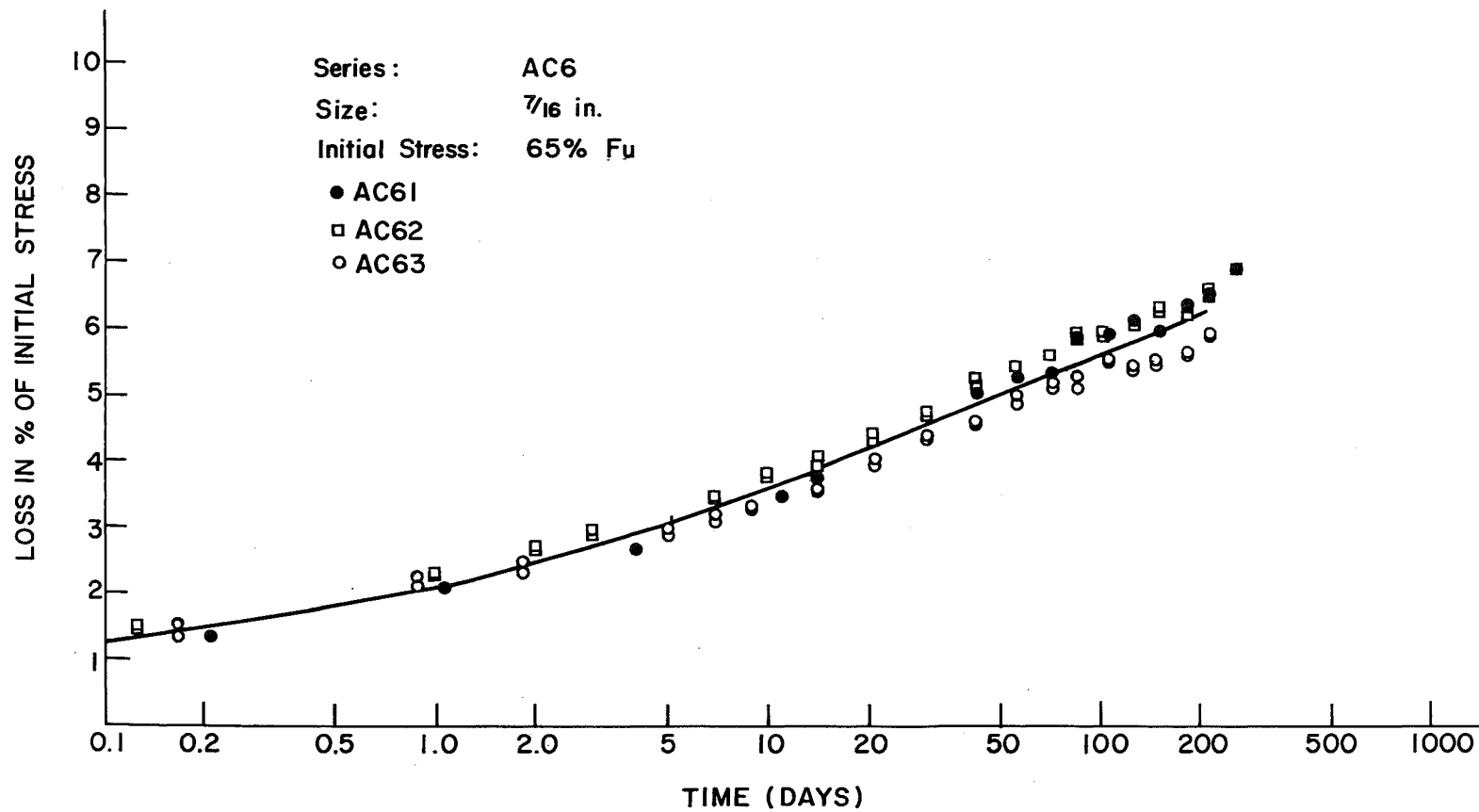


Fig. 4 Relaxation Loss Data Series AC6



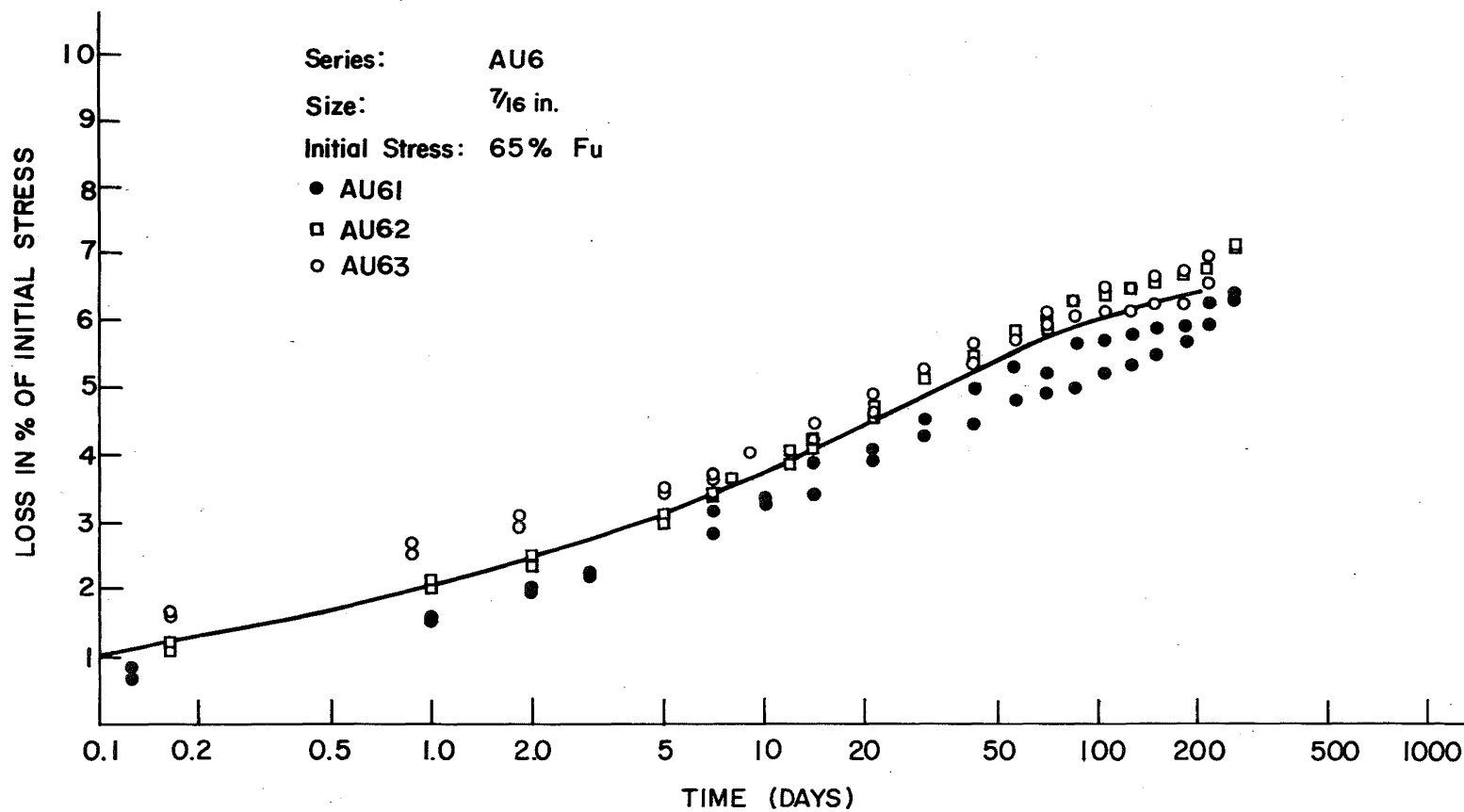


Fig. 5 Relaxation Loss Data Series AU6

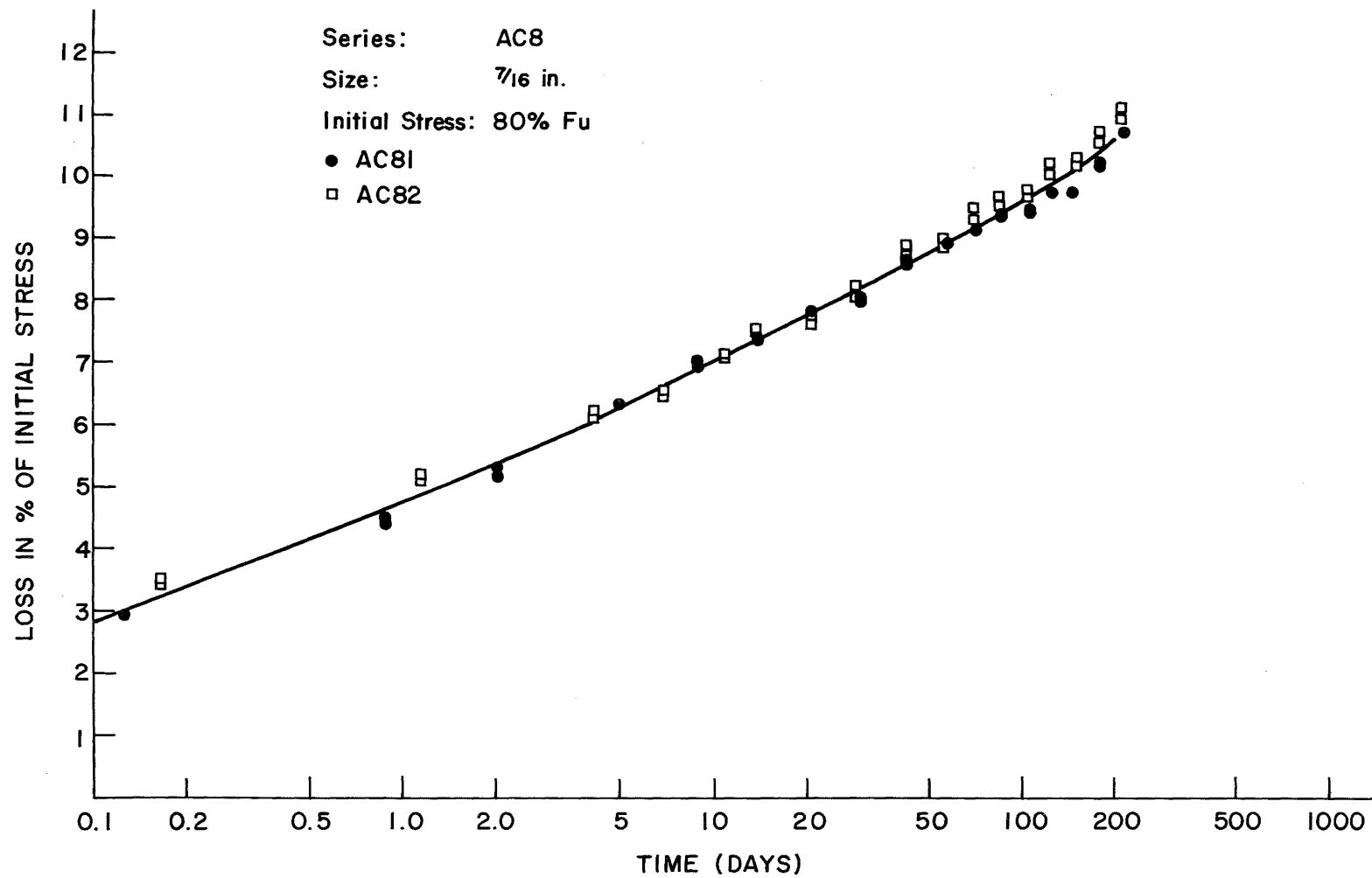


Fig. 6 Relaxation Loss Data Series AC8

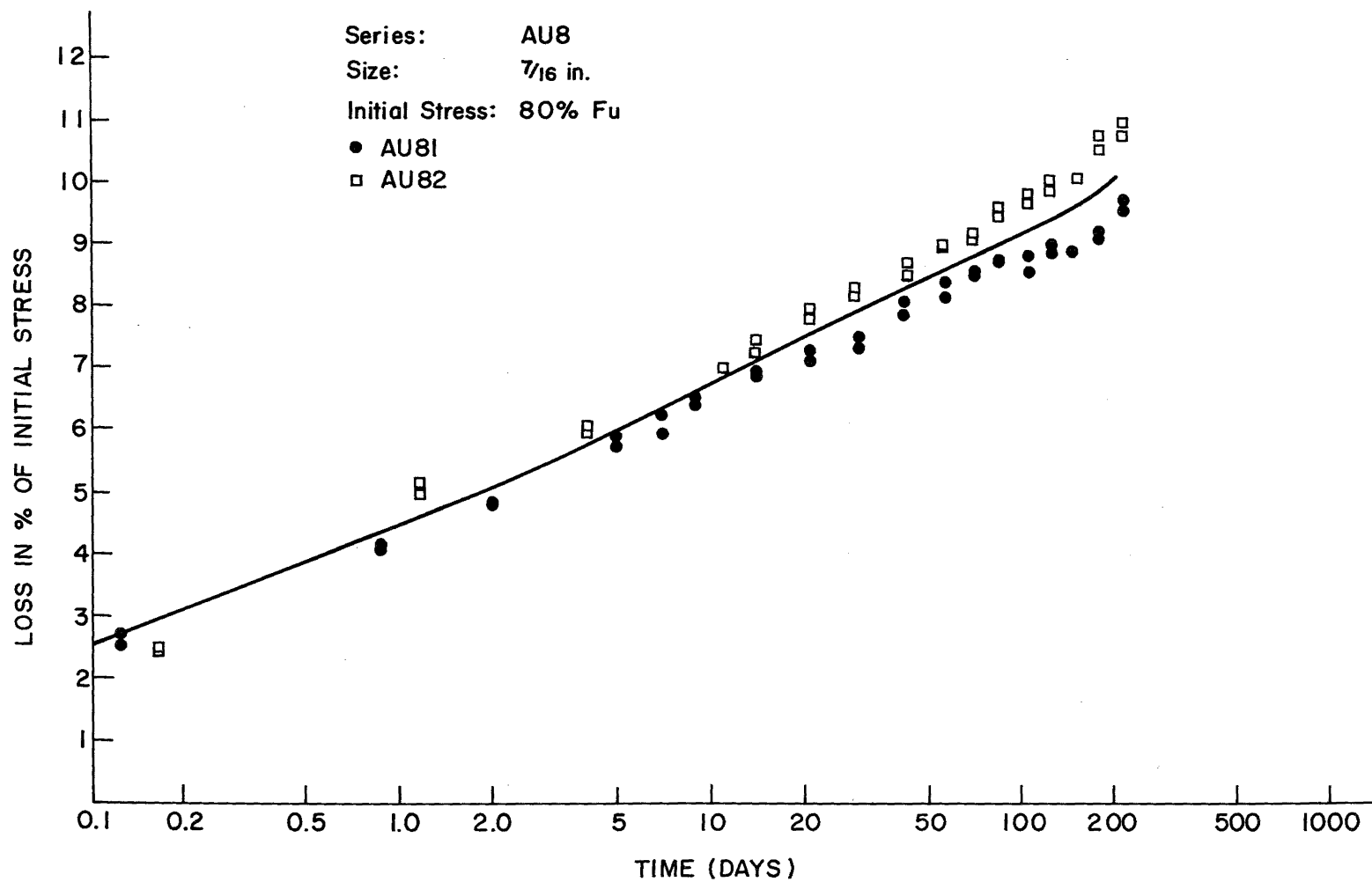


Fig. 7 Relaxation Loss Data Series AU8

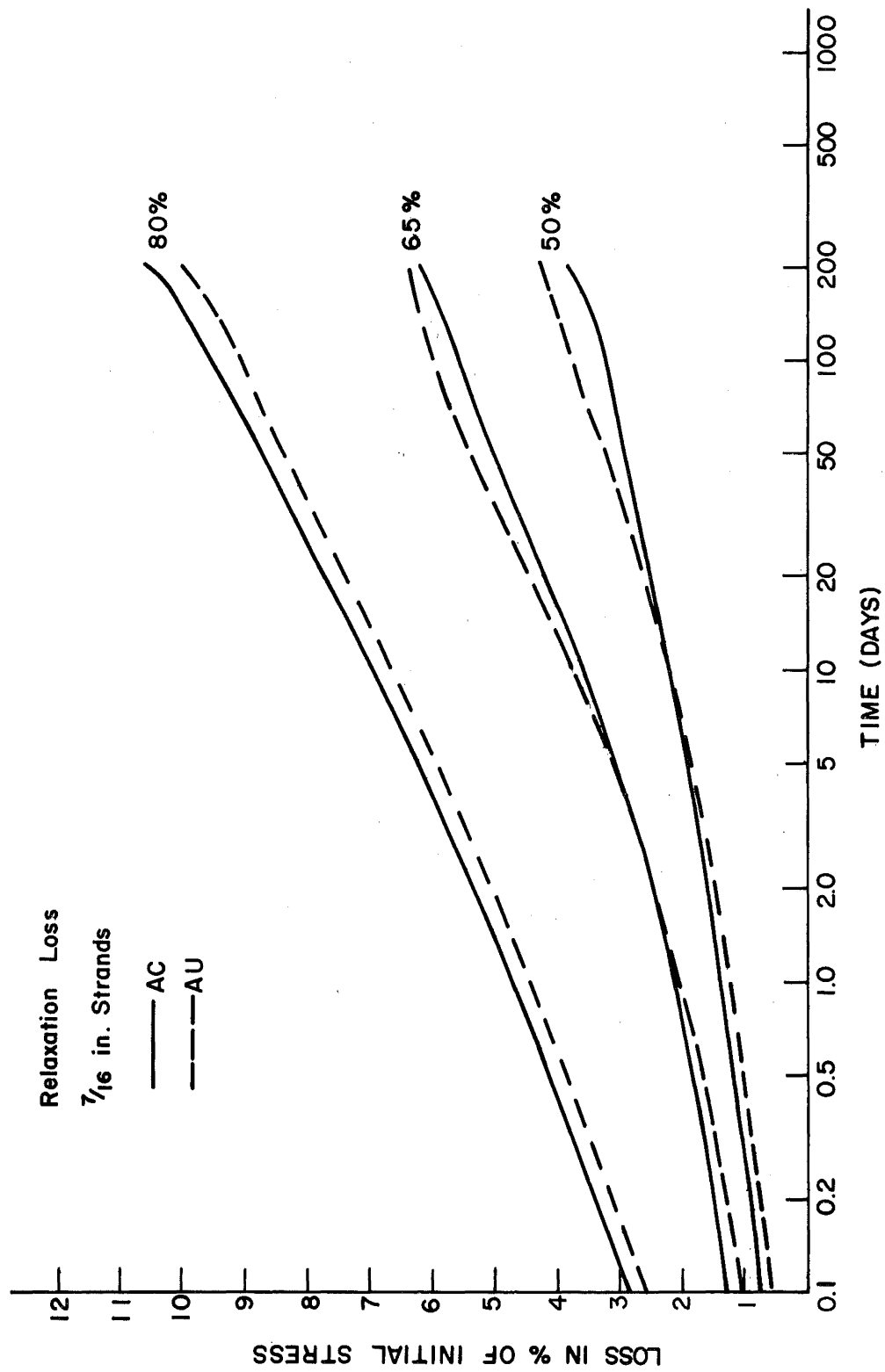


Fig. 8 Relaxation Loss of 7/16 in. Strands